Into the shape of neutron deficient polonium (Z=84) isotopes with in-source laser spectroscopy at the CERN-ISOLDE facility

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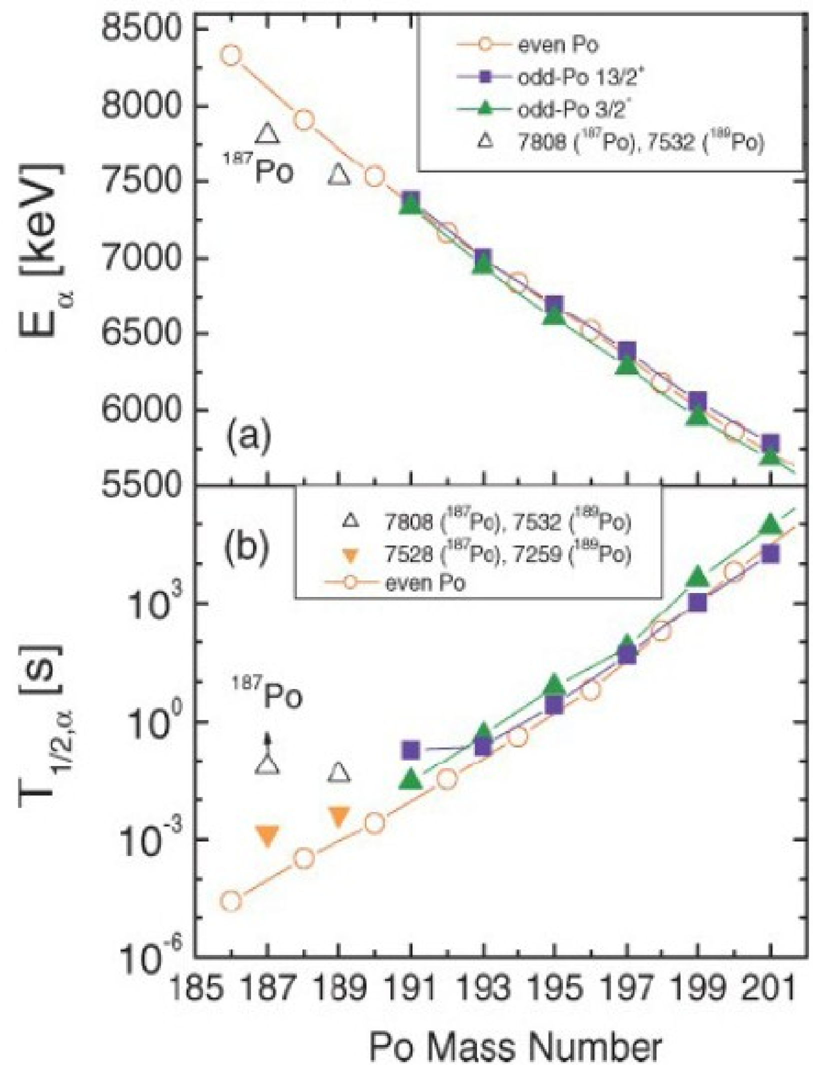
Outline

- Motivation
  - Interest in polonium
  - Mean-square charge radius of polonium
- Technique
  - Laser ionisation of polonium at the CERN-ISOLDE RILIS
  - IS456: Laser spectroscopy via nuclear spectroscopy
- Results
  - New nuclear spectroscopic information
  - Isotope shift of the even polonium isotopes $^{194\text{-}196\text{-}198\text{-}200\text{-}202\text{-}204}$Po
  - Hyperfine structure of the odd polonium isotopes $^{193\text{-}195\text{-}197\text{-}199}$Po

Motivation: α decay of Po

- Smooth dependence of the α energy and the partial half-lives.
- First discrepancy from this trend at ^{191m}Po:
  - onset of oblate deformation
- ^{187,189}Po deviate even more from the trend:
  - prolate deformation
- The even isotopes remain on the smooth trend.
  - spherical nuclei

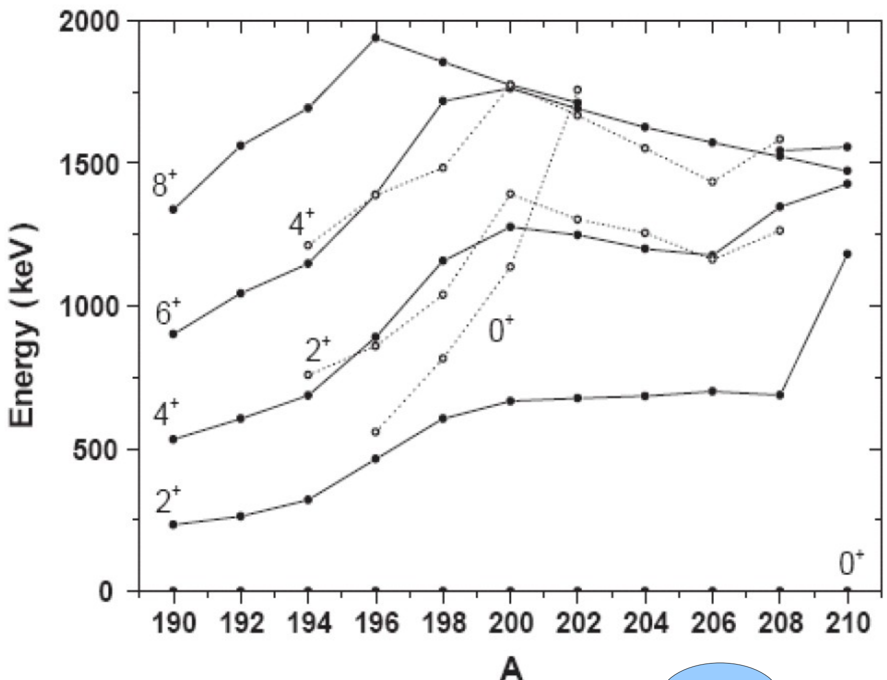
?! SHAPE STAGGERING / COEXISTENCE ?!

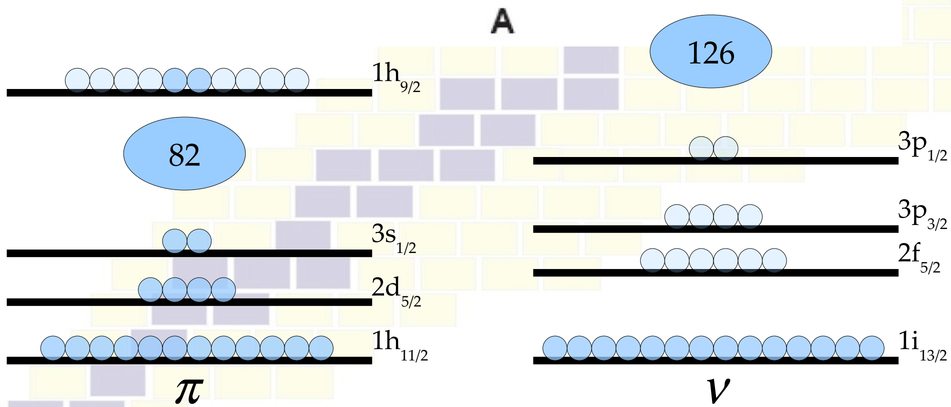


A.N.Andreyev et al., PRC73:044324 (2006)

Motivation: γ decay of Po

K.Van de Vel et al., EPJA17:167-171 (2003)

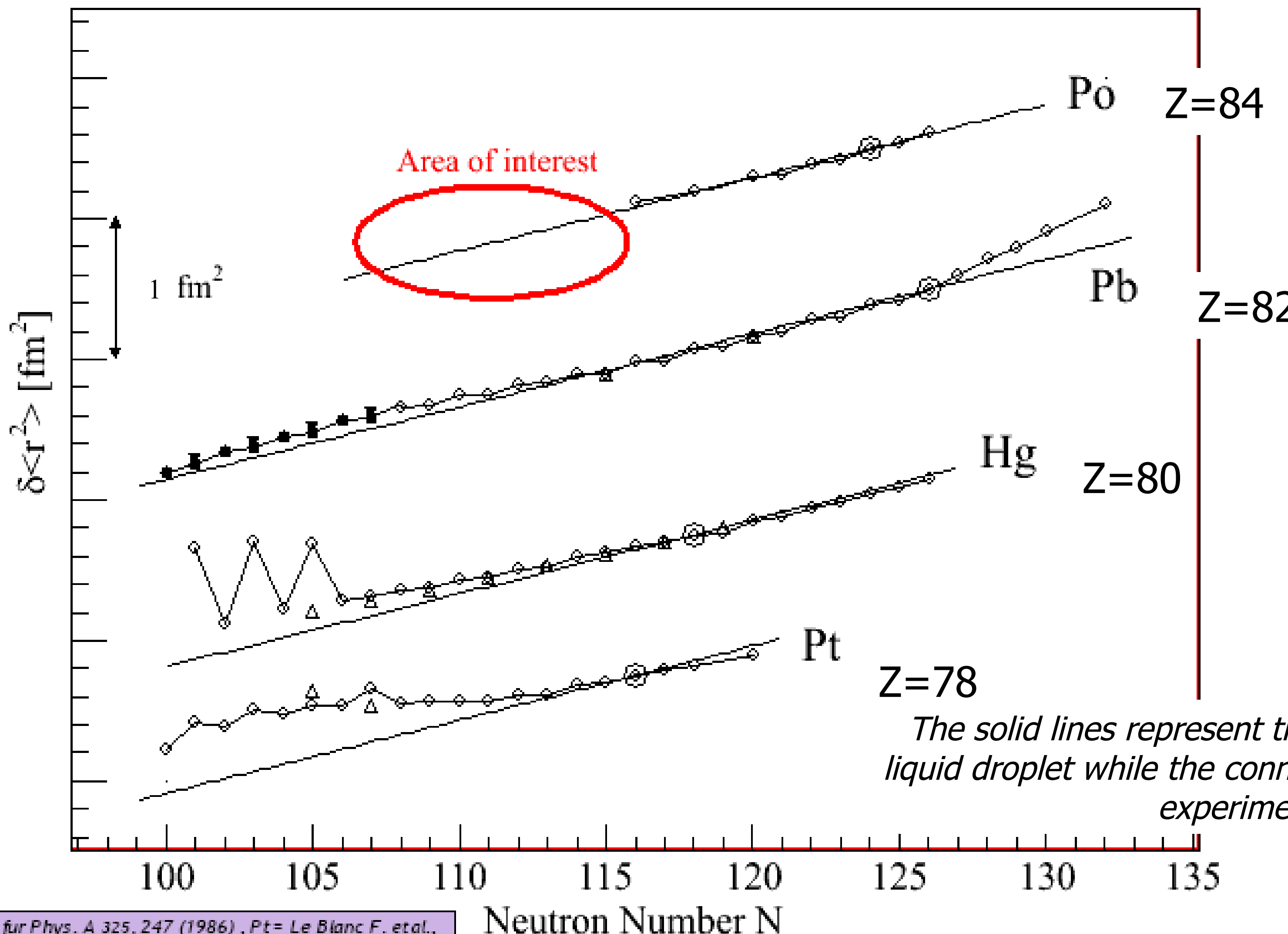




- Close to the shell closure *N*=126, one can see Po as a closed-shell *Z*=82 Pb core with a pair of protons: (Pb⊕2p).
- This nice pictures works well until N=114 where the behaviour changes.
- The intruding 0_2^+ state cannot be explained in this model at all.

?! CONFIGURATION MIXING ?!

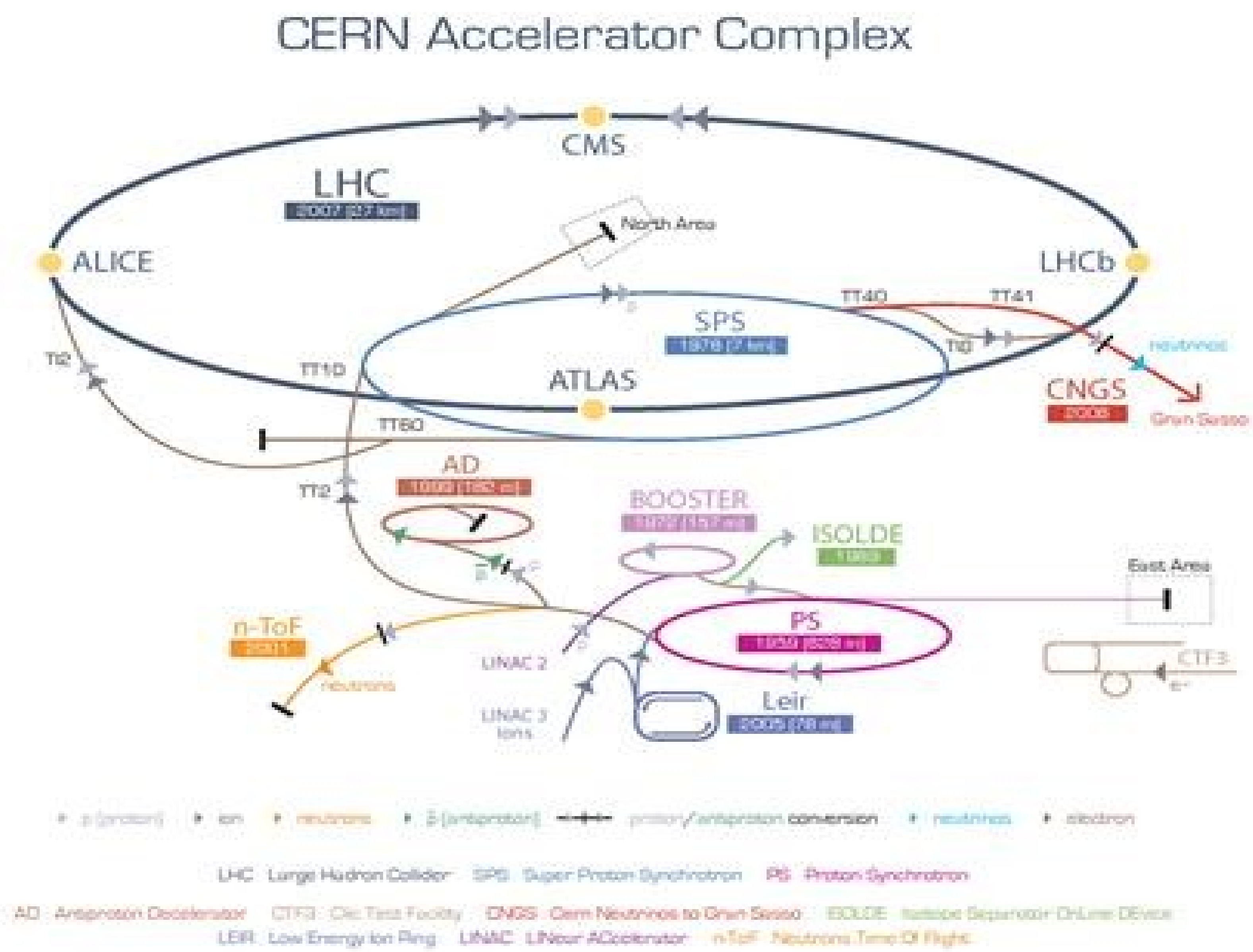
Mean-square charge radius $\delta\langle r^2\rangle$



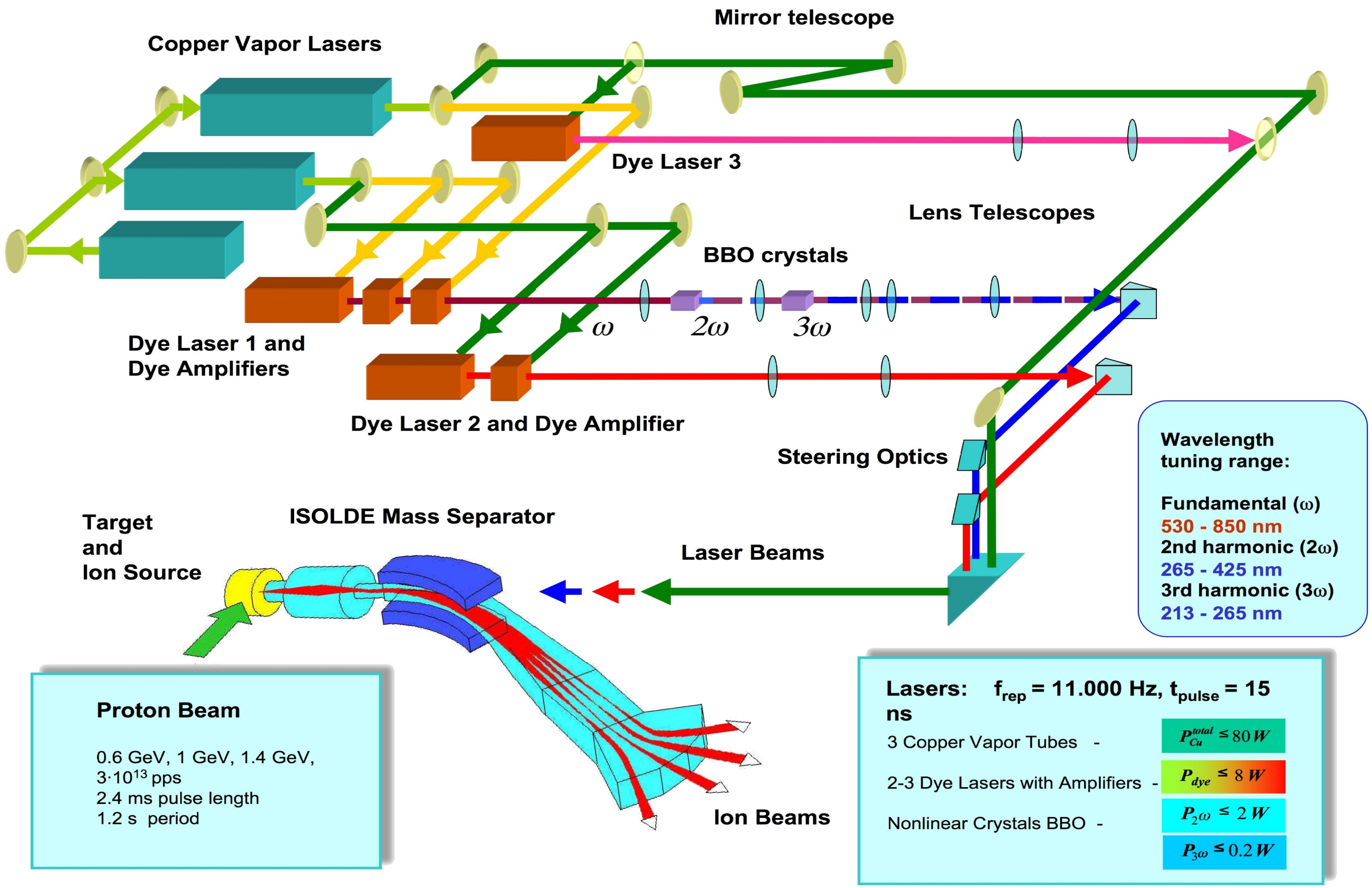
The solid lines represent the evolution of a liquid droplet while the connected points are experimental data points.

Hg = G. Ulm et al., Zeit. fur Phys. A 325, 247 (1986) , Pt = Le Blanc F. et al., Phys. Rev. C 60, 054310 (1999), Pb = De Witte H. et al., PRL (2007), accepted, Po = Kowalewska D. et al, Phys. Rev. A 44, 1442R (1991)

CERN


CERN Accelerator Complex
CMS
LHC
ALICE
LHCb
North Area
SPS
ATLAS
TT40
TT41
TI8
TI2
TT10
TT60
TT2
CNGS
Gran Sasso
neutrinos
AD
BOOSTER
ISOLDE
East Area
n-ToF
neutrons
PS
LINAC 2
LINAC 3
Ions
Leir
CTF3
LHC Large Hadron Collider
SPS Super Proton Synchrotron
PS Proton Synchrotron

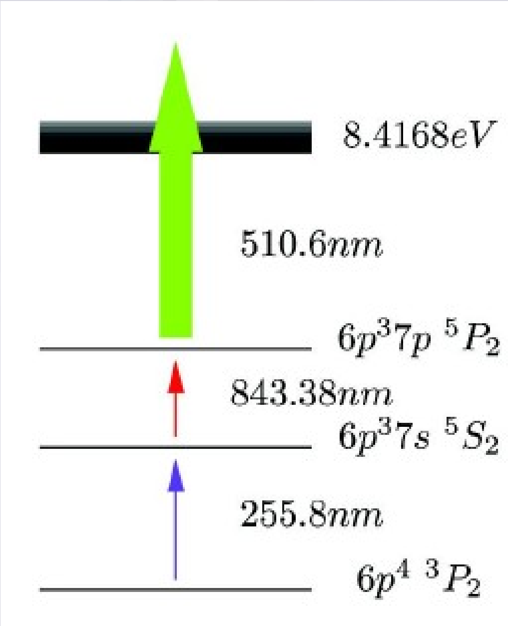
ISOLDE RILIS



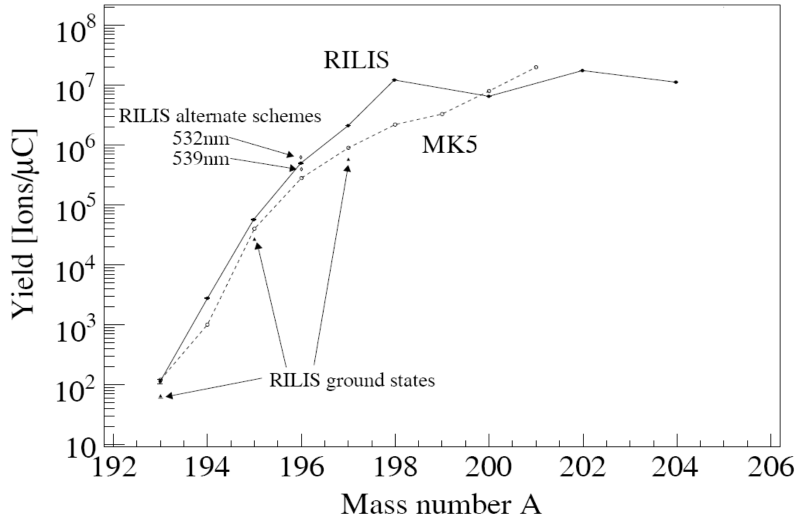
ISOLDE – Isotope Separation On Line DEvice

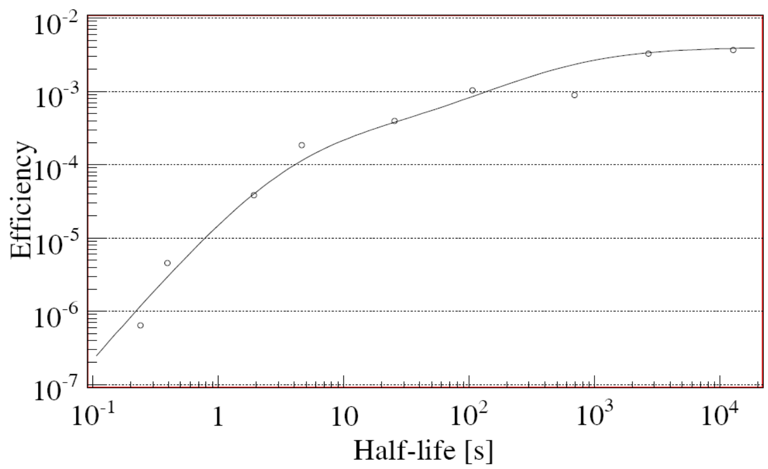
RILIS – Resonant Ionisation Laser Ion Source

Laser ionisation of Po



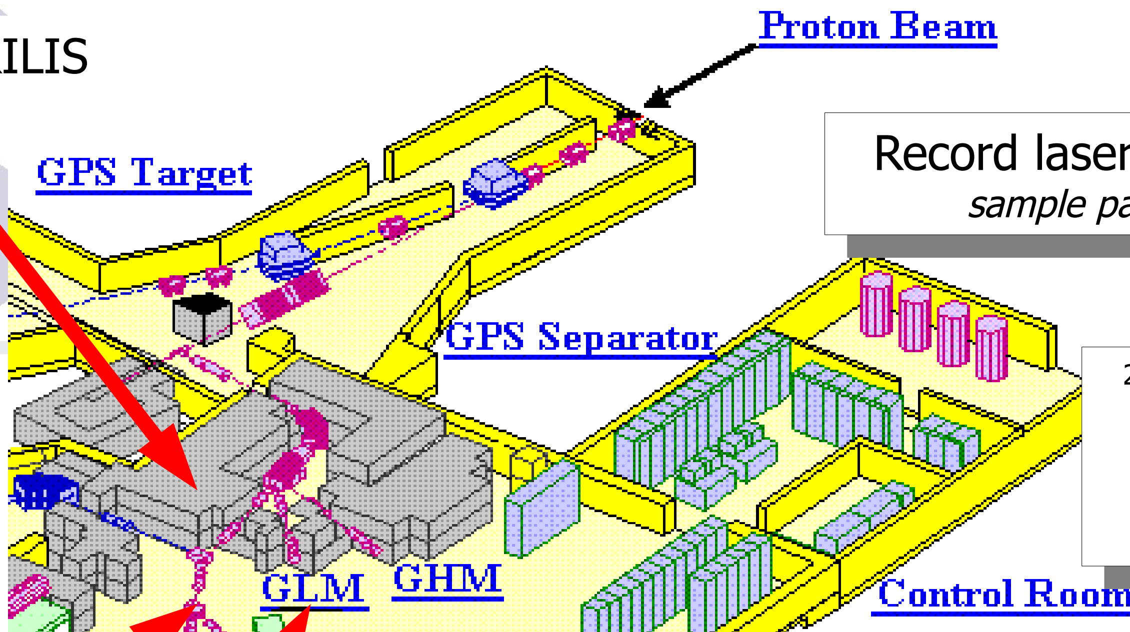
Polonium laser ionization scheme





IS456 with the ISOLDE-RILIS

ISOLDE-RILIS laser



ISOLDE tape station
β / γ

IKS Windmill
α

- Simultaneous measurement of an isotope of interest and a reference isotope while taking beam at both GLM and CA0.

Protons on target
sample source

Record laser frequency
sample parameter

^{20x}Po at CA0
βγ-decay accumulation

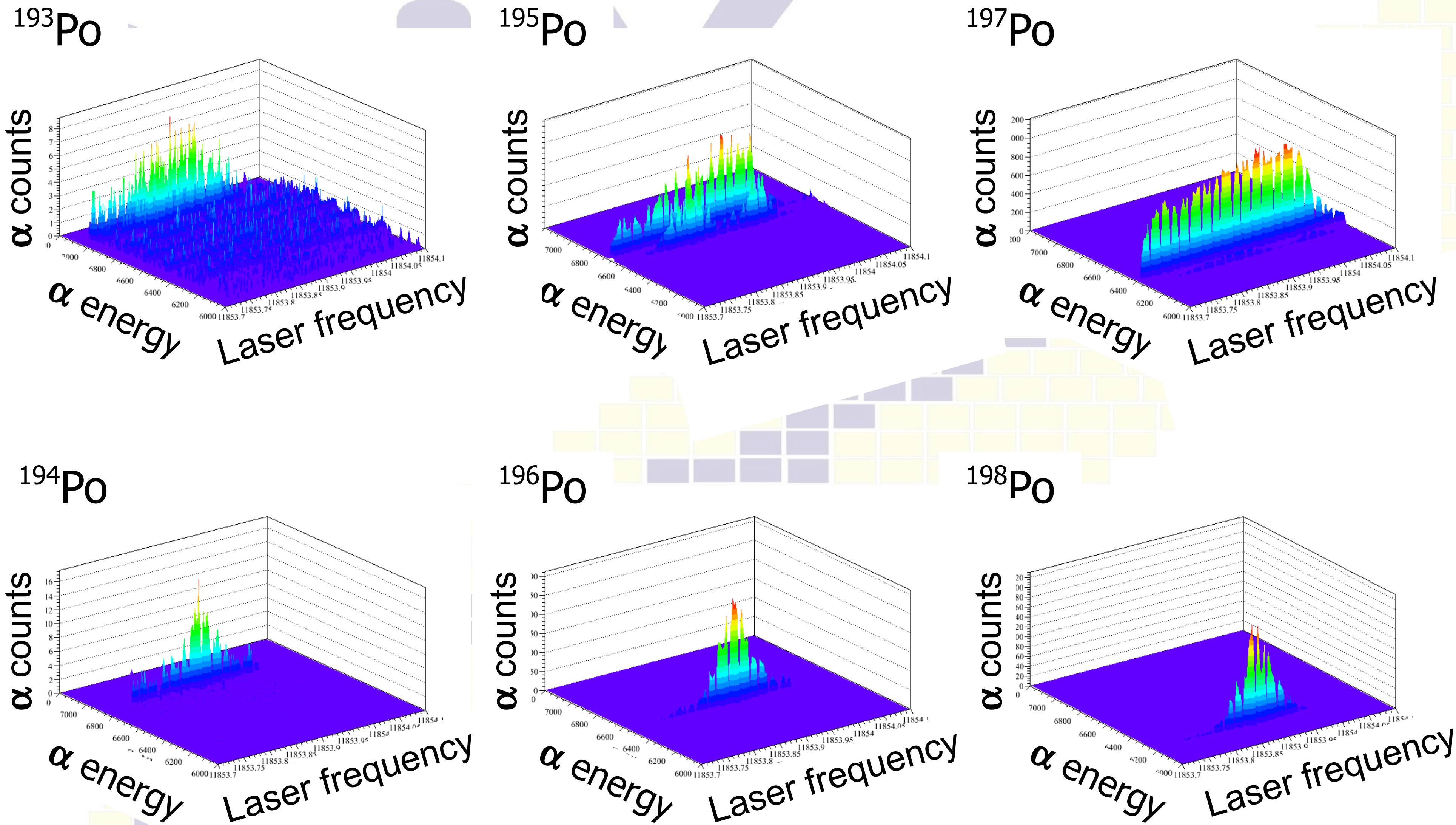
^{19x}Po at GLM
α-decay accumulation & measurement

Tape transport & measurement

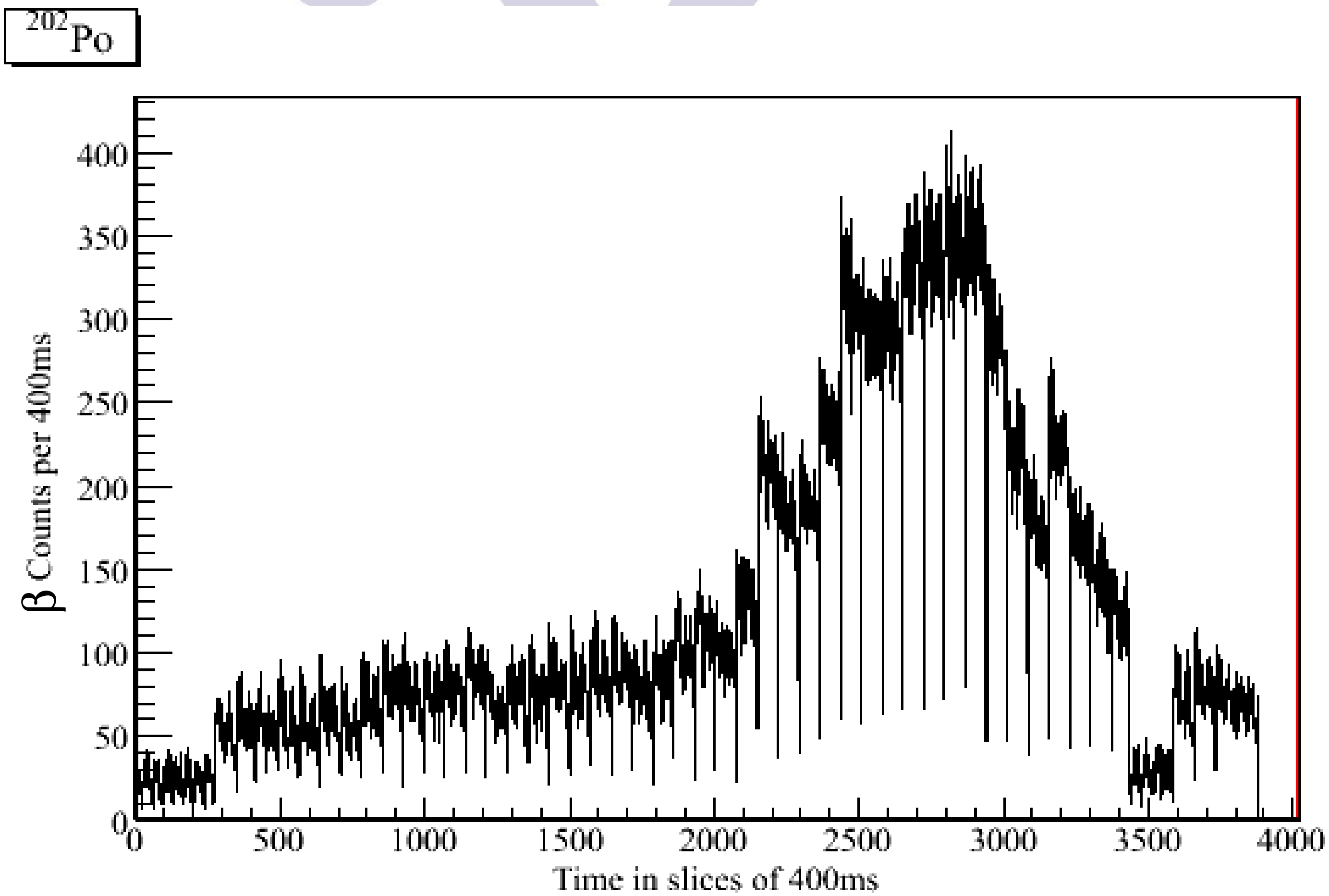
Wheel rotation & delay

Change laser frequency
wait for stabilisation

Analysis: typical α data



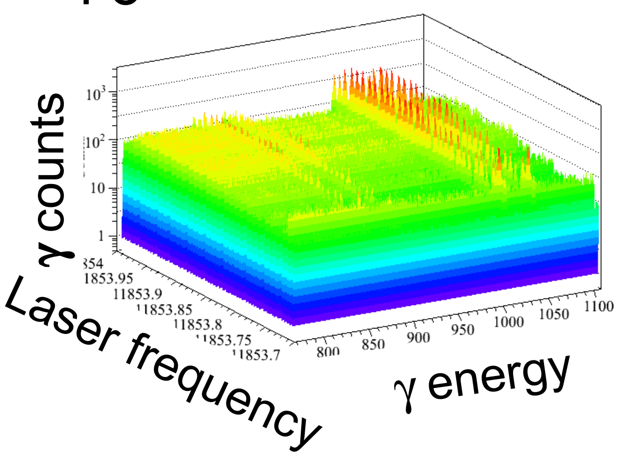
Analysis: typical β data



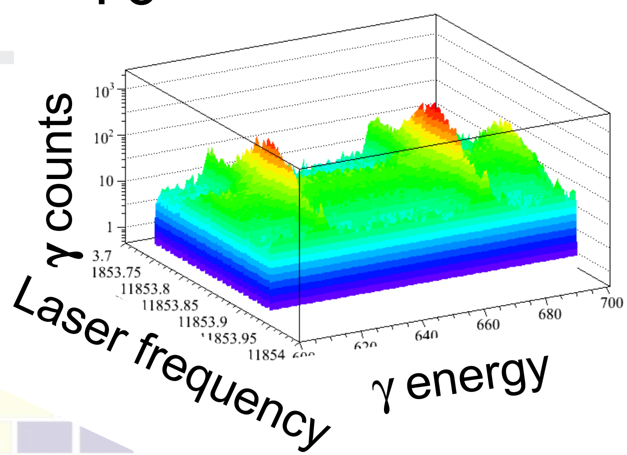
Relation between time and frequency in off-line analysis

Analysis: typical γ data

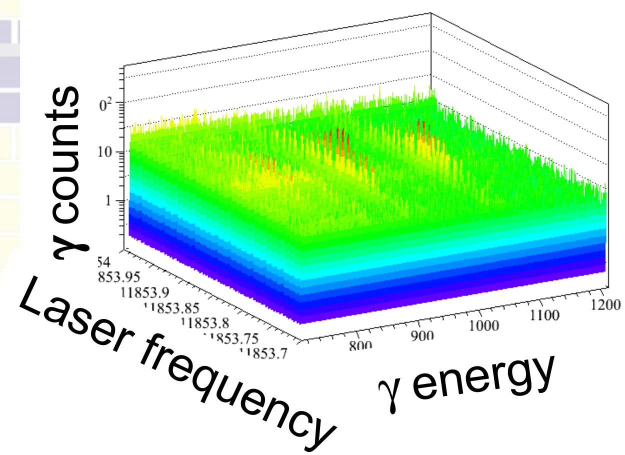
^{199}Po



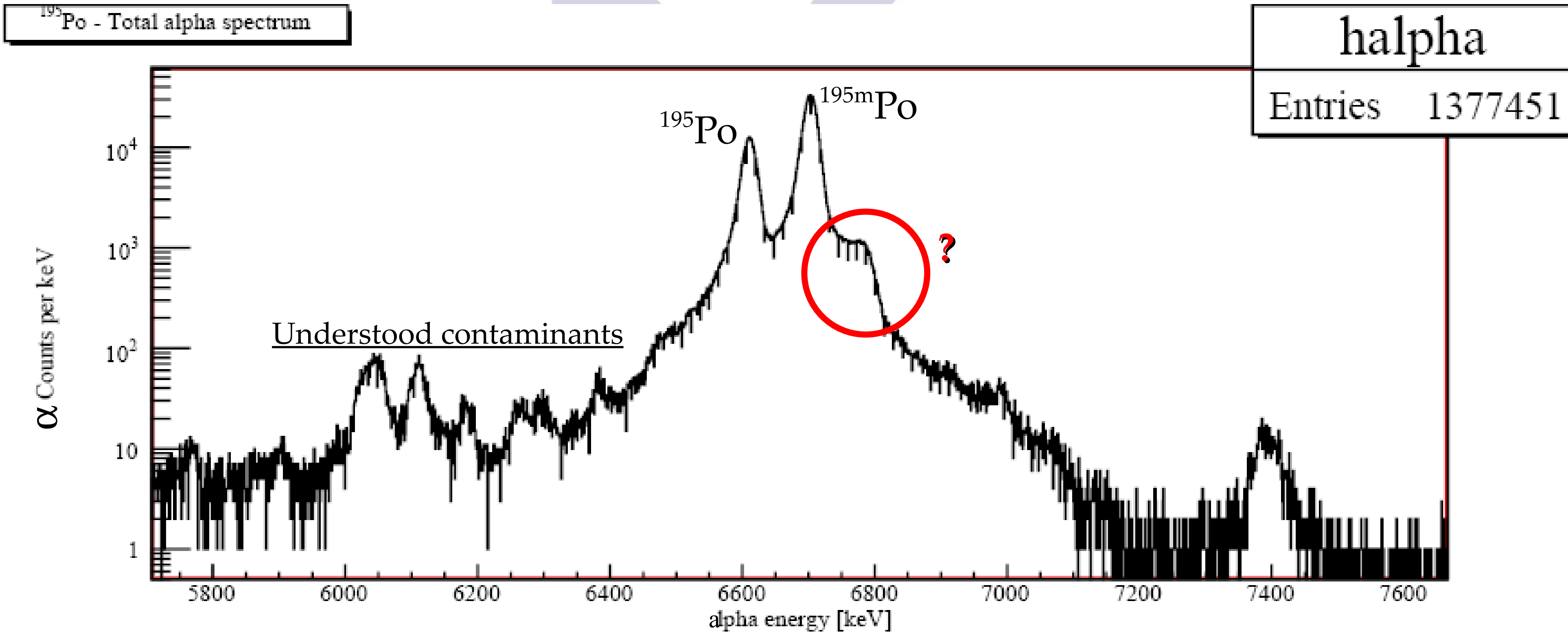
^{200}Po

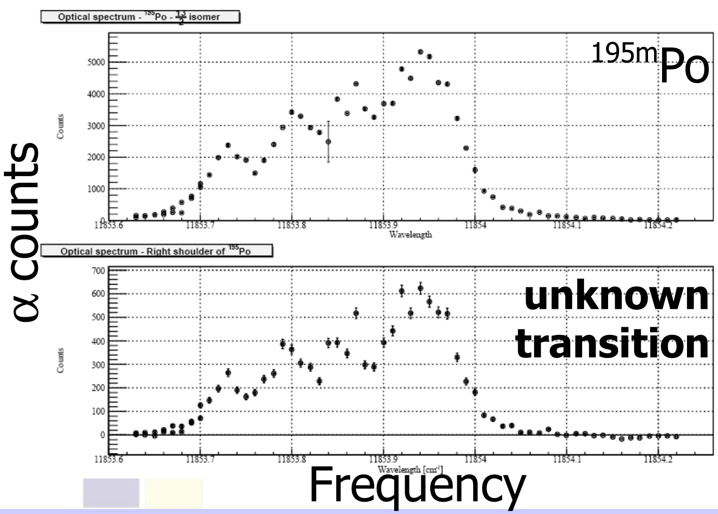


^{204}Po

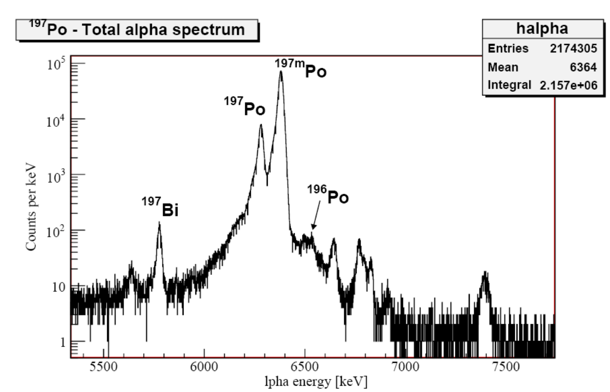


An unexpected result in ^{195}Po

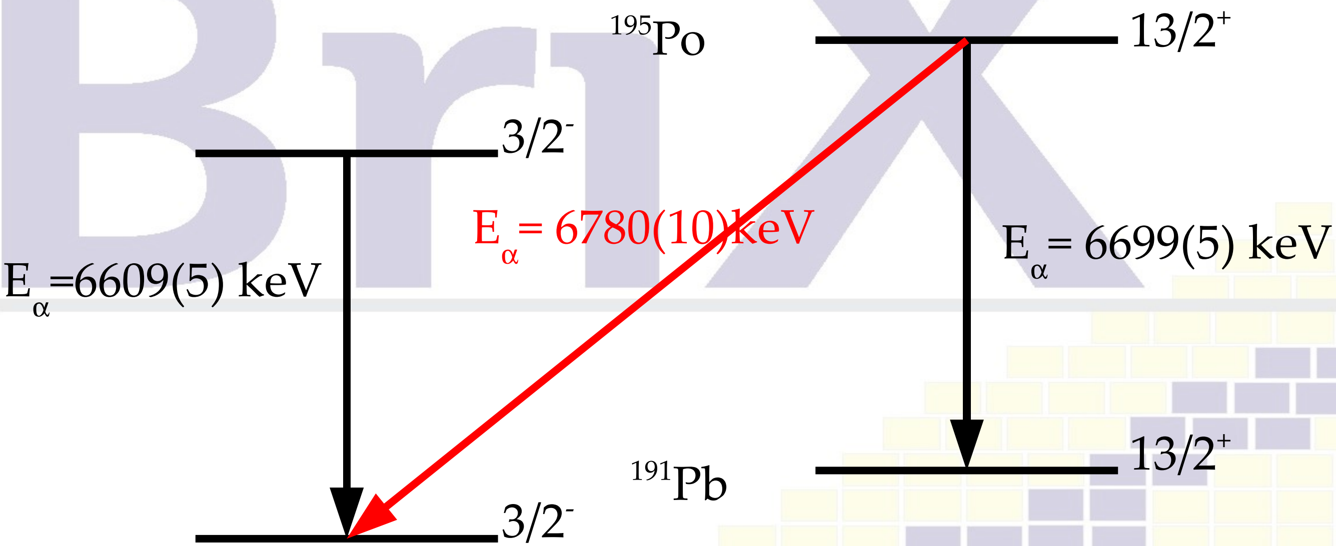




- Unidentified alpha peak,
- Unexplained high-energy tail,
- Similar frequency dependence of the shoulder as the high spin isomer.

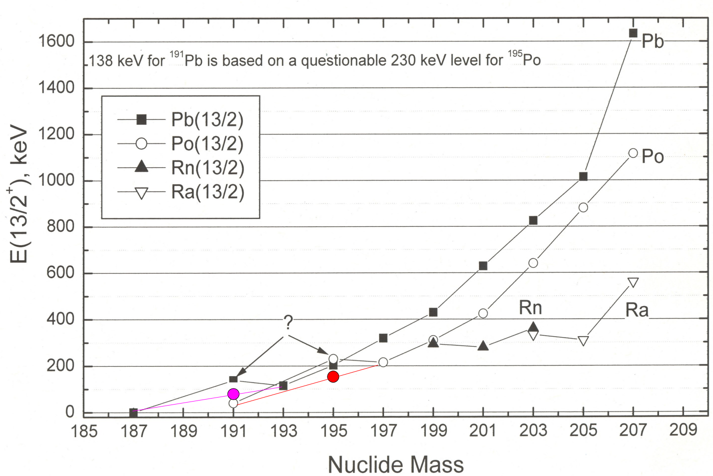


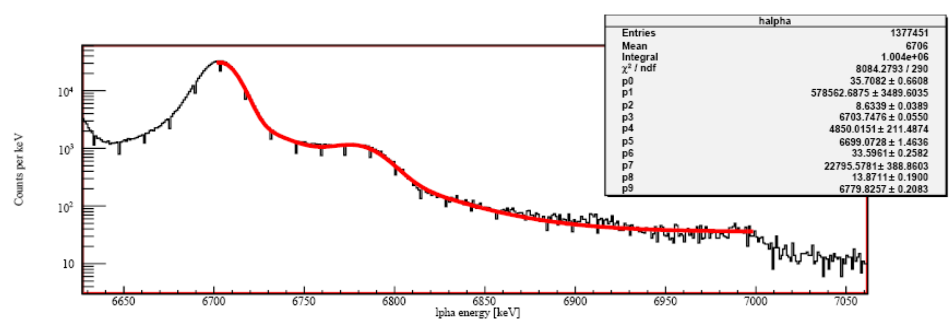
Cross-over decay in ^{195}Po



- $E(13/2^+ - ^{195}Po) = 175(11)$keV
- $E(13/2^+ - ^{191}Pb) = 83(11)$keV

- Those values fit with the systematics and solve a problem almost 20 years old...

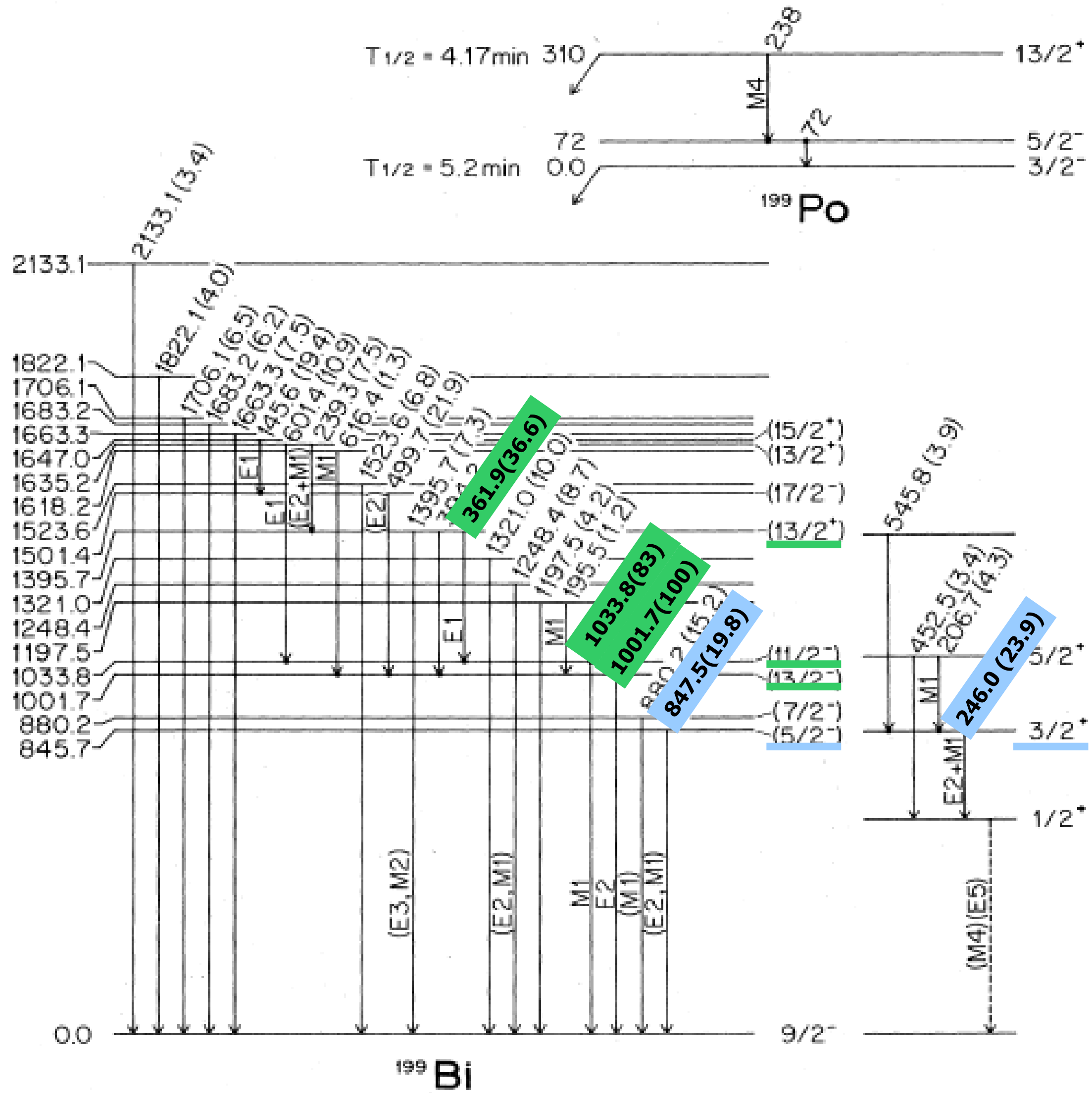




Relative feeding of ^{199}Bi in the decay of ^{199}Po

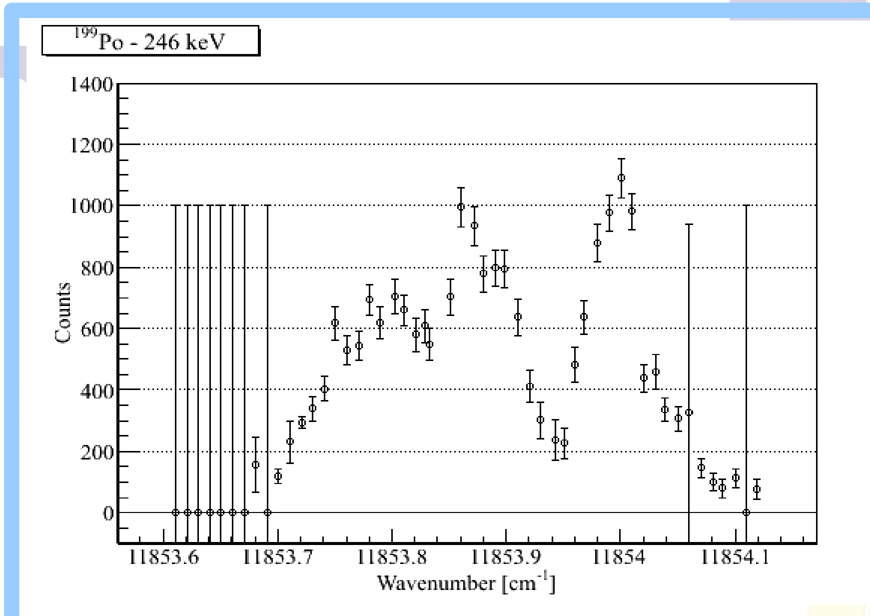
from ^{199}Po

from ^{199m}Po



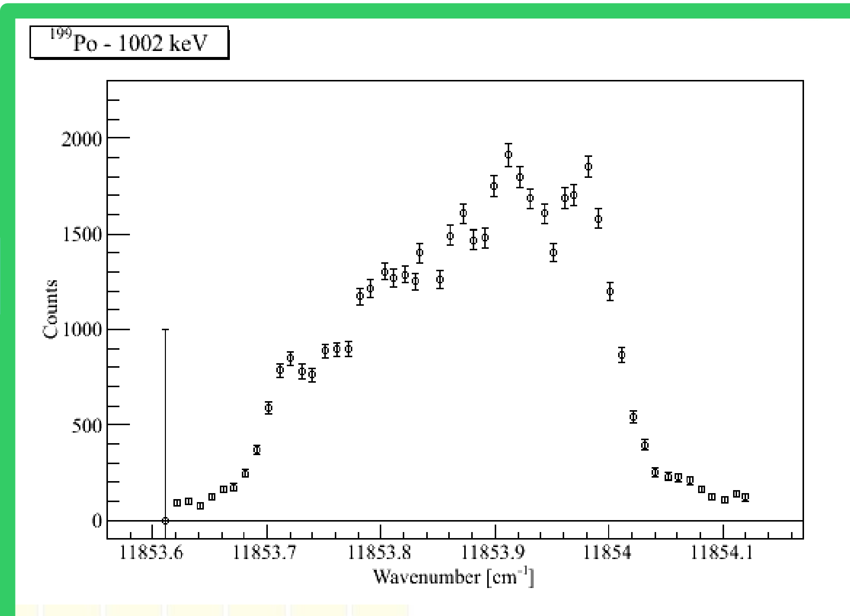
R.E.Stone et al., PRC31:582-592 (1985)

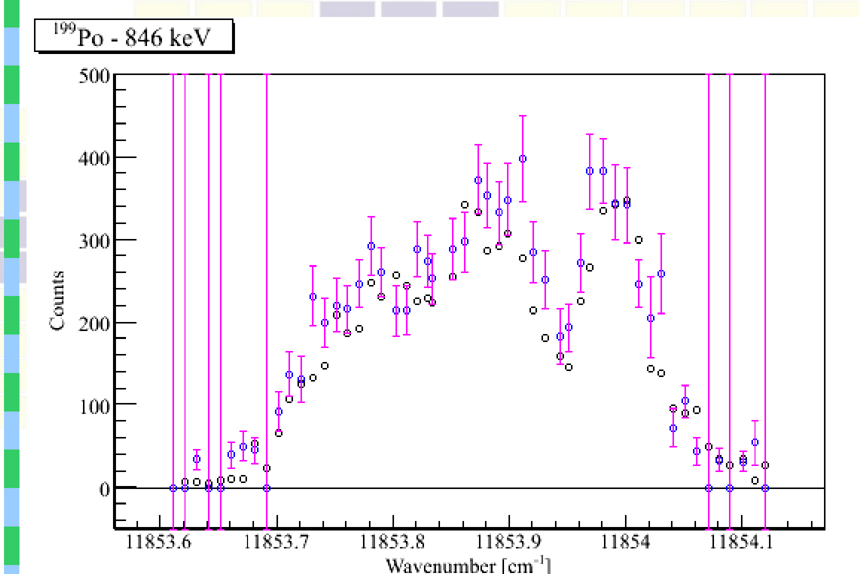
Relative feeding of ^{199}Bi in the decay of ^{199}Po



from ^{199m}Po

from ^{199}Po



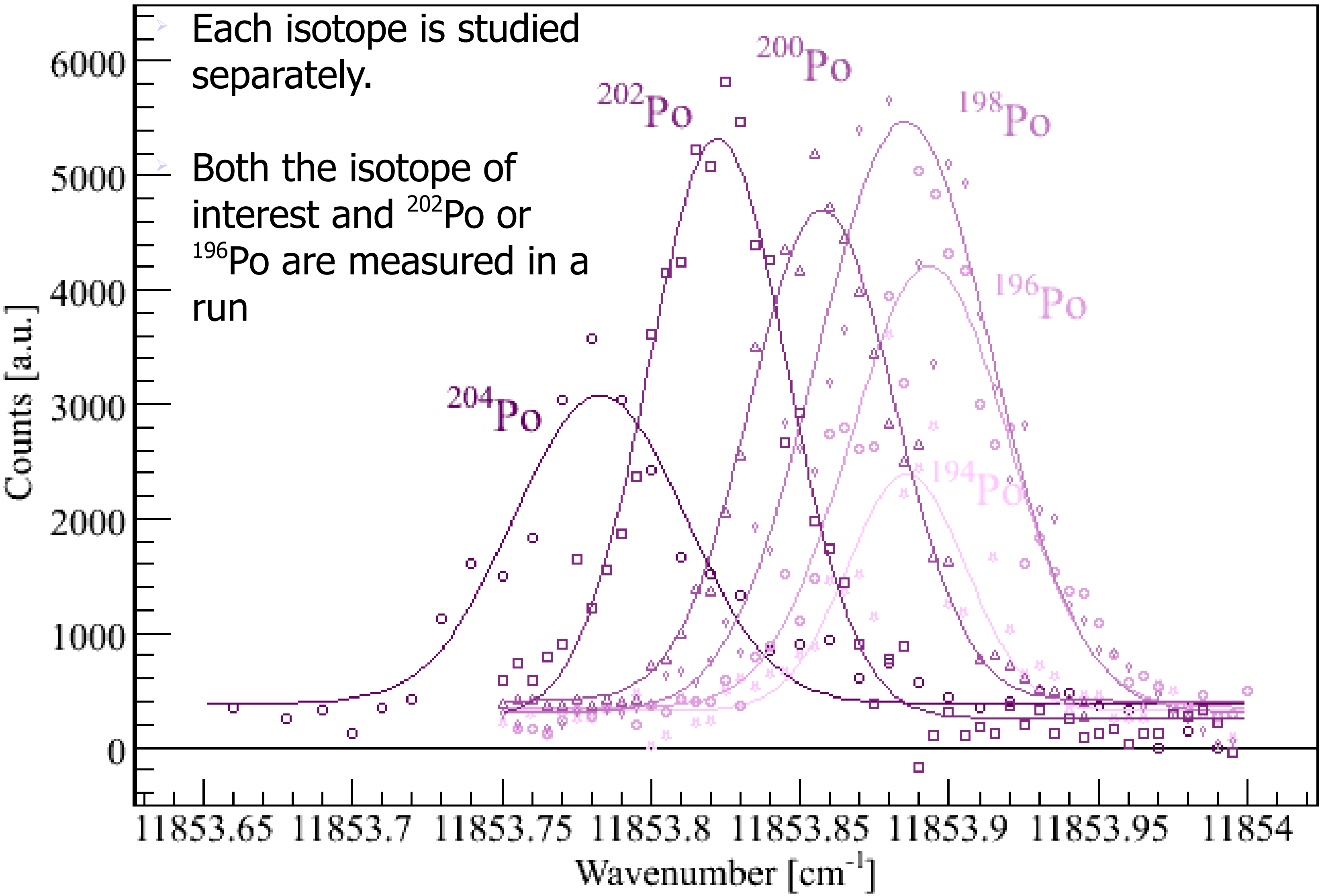


The optical transition determined using the 846 keV γ transition from the (5/2$^-$) level is neither that of ^{199}Po nor that of ^{199m}Po.

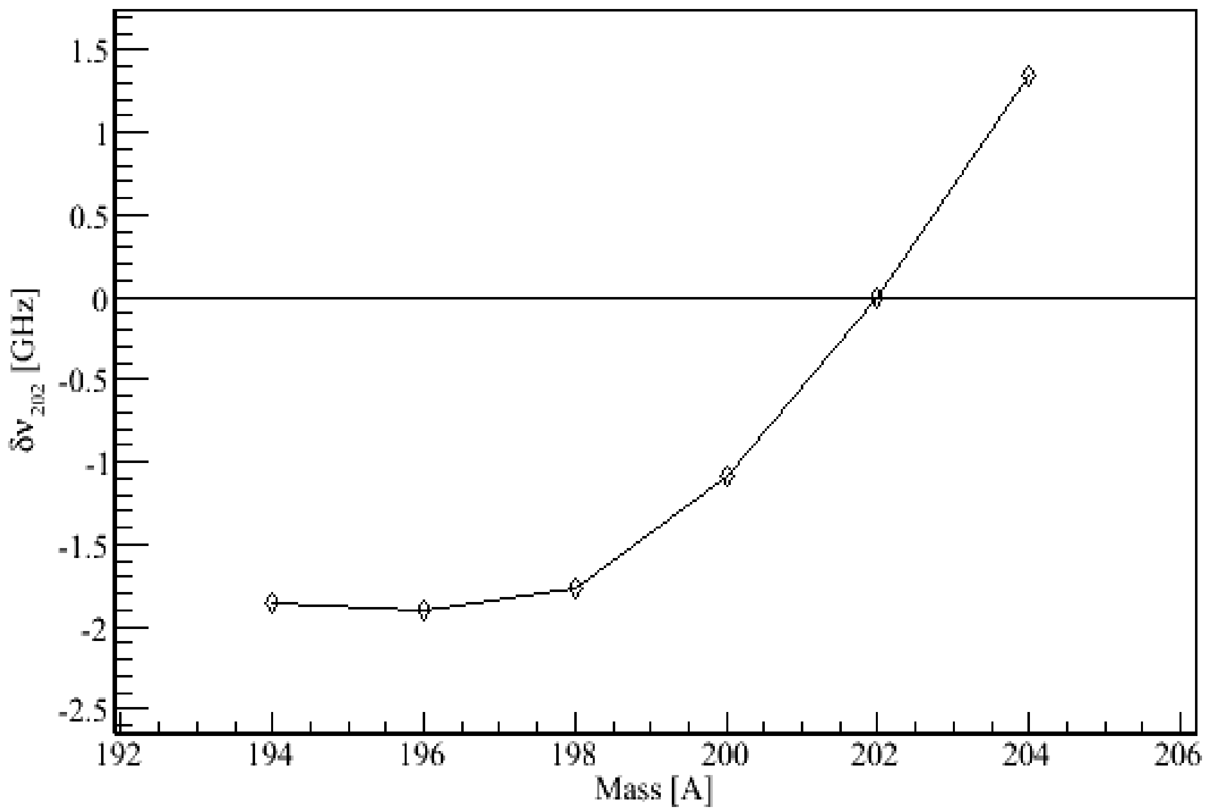
It is actually a linear combination of both the profiles shown on the top. From the relative strengths and the coefficients one can reconstruct the relative feeding in the decay scheme.

Isotope shift in even-even nuclei

- Each isotope is studied separately.
- Both the isotope of interest and ^{202}Po or ^{196}Po are measured in a run

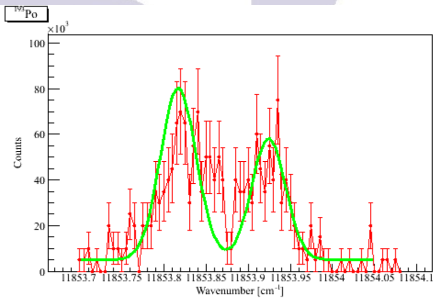
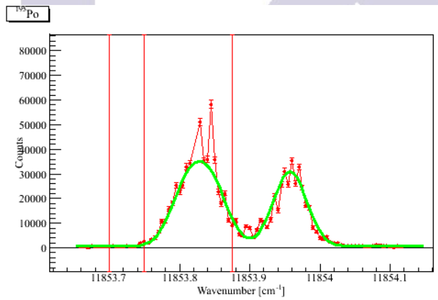
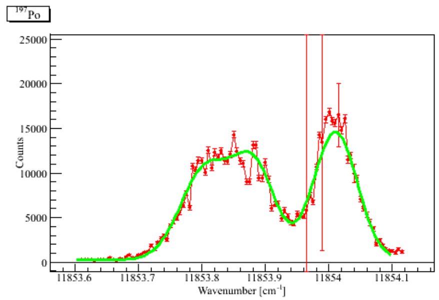
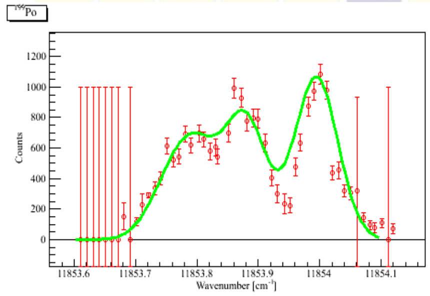
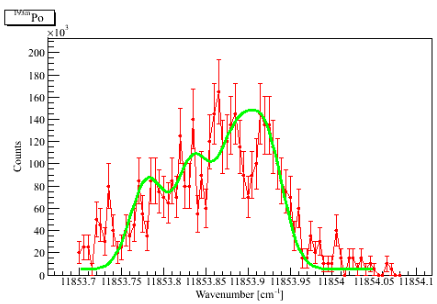
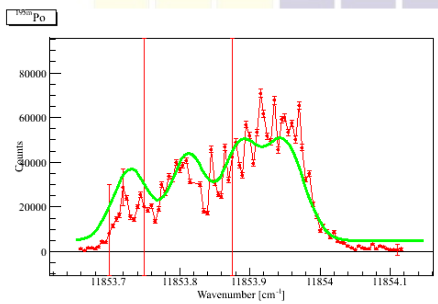
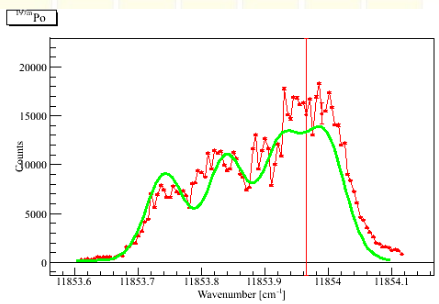
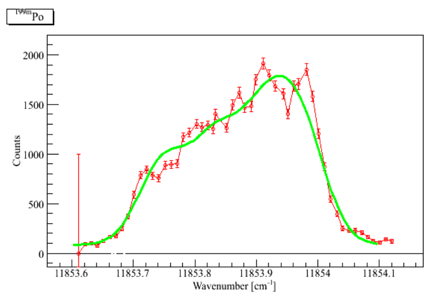


Isotope shift of even-even nuclei



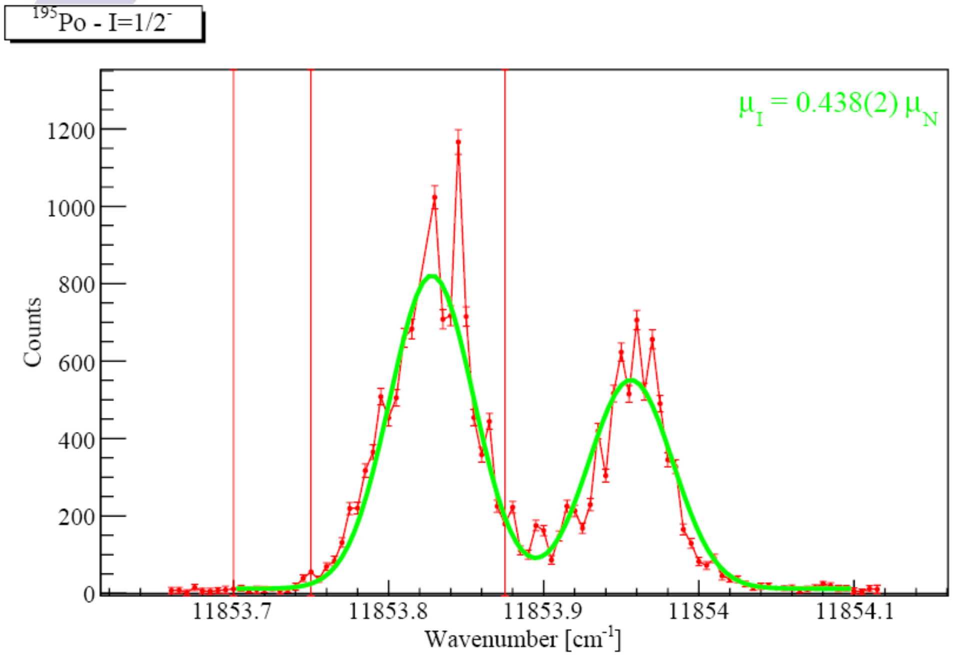
- All isotopes from ^{196}Po to ^{204}Po seem to align on a trend from which ^{194}Po clearly deviates.
- Only comparison of the $\delta\langle r^2\rangle$ can however yield clear information linked with the heavier isotopes.

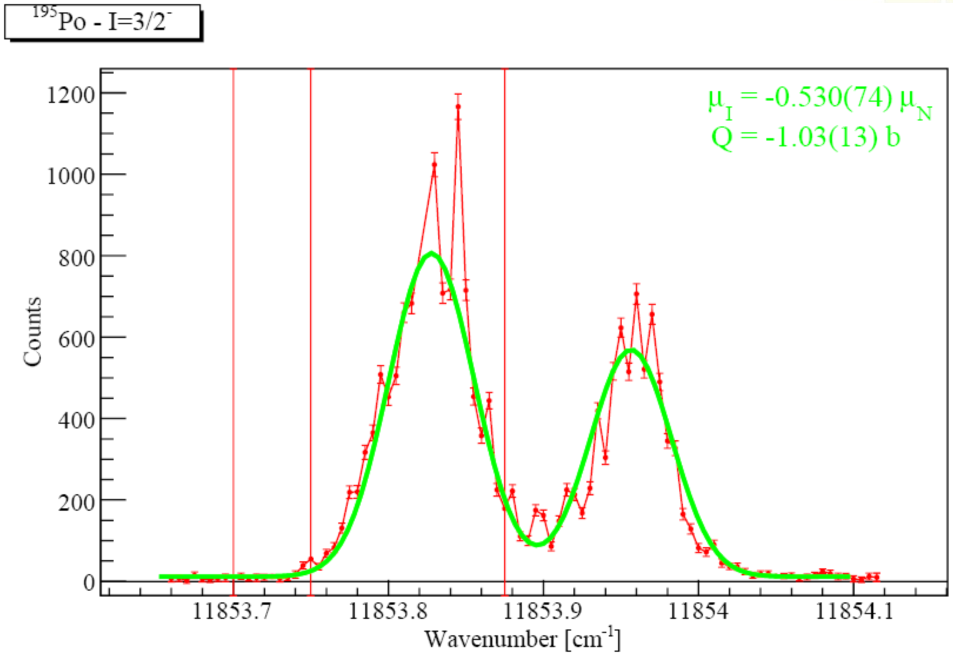
Hyperfine structure of Po

	^{193}Po	^{195}Po	^{197}Po	^{199}Po
$I^{\pi} = (3/2^{-})$				
$I^{\pi} = (13/2^{+})$				

HFS of ^{195}Po

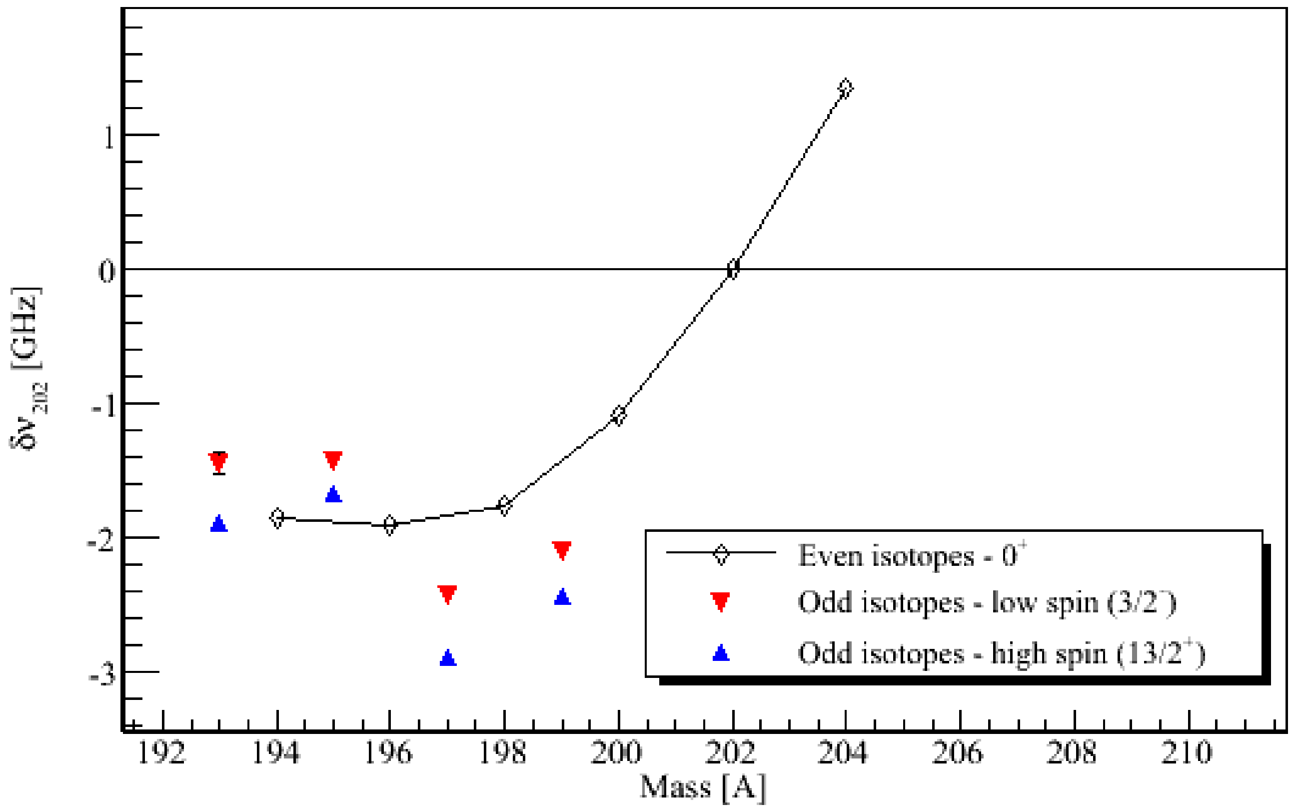
- From the optical spectrum, it would seem this isotope has a nuclear spin I=1/2$^-$ yielding only two peaks to the hyperfine structure.
- The following magnetic dipole moment is, however, positive.
- The electric quadrupole moment cannot be determined.





- Assuming a spin I=3/2- from a decay and from the systematics, three peaks have to be clustered in one to obtain this optical spectrum, indicating a very large quadrupole parameter.
- The magnetic dipole moment is negative, agreeing with the picture of a single neutron in the $i_{13/2}$ orbital.

Isotope shift in the odd nuclei

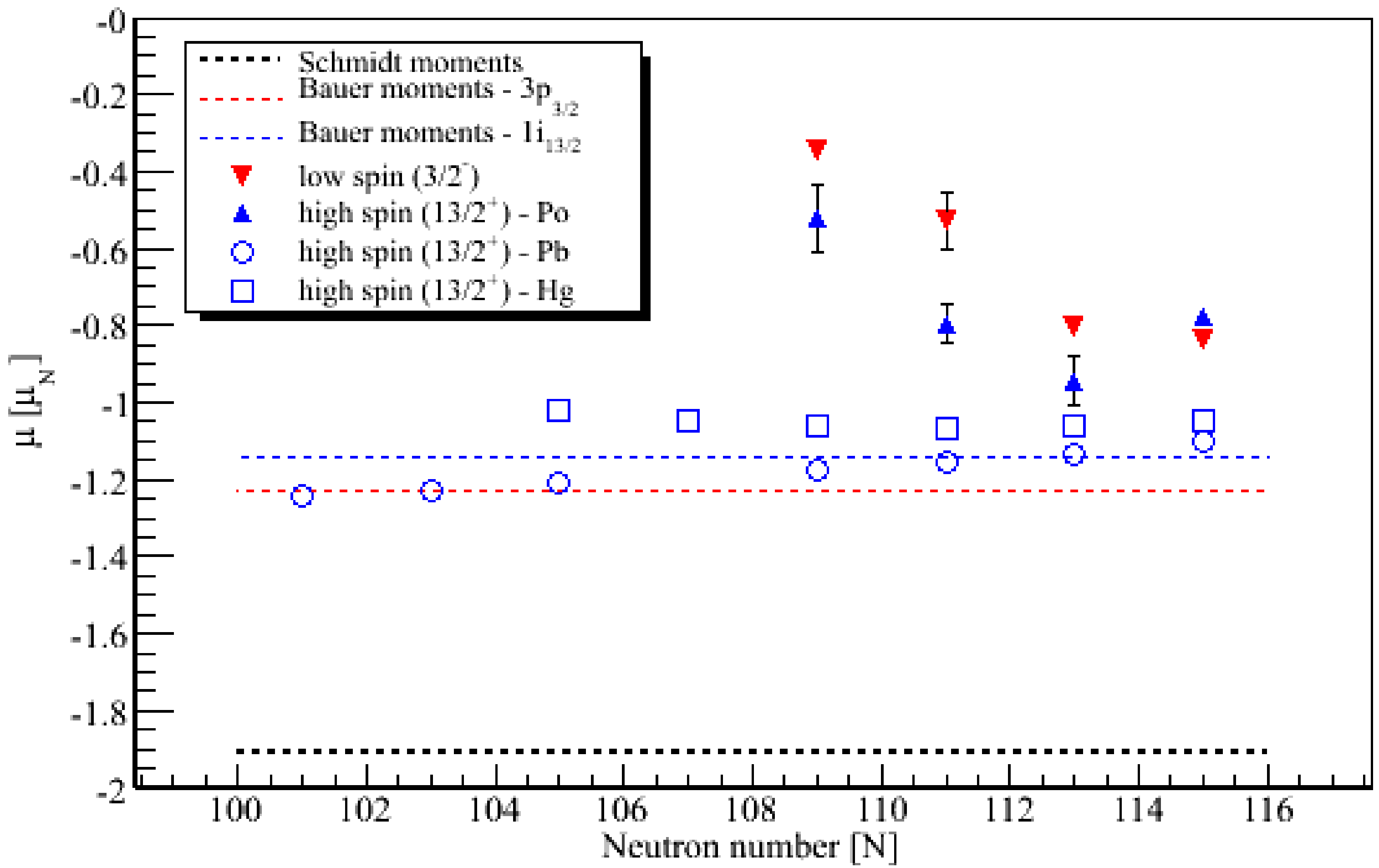


The odd-even staggering seems to inverse, as observed in Hg.

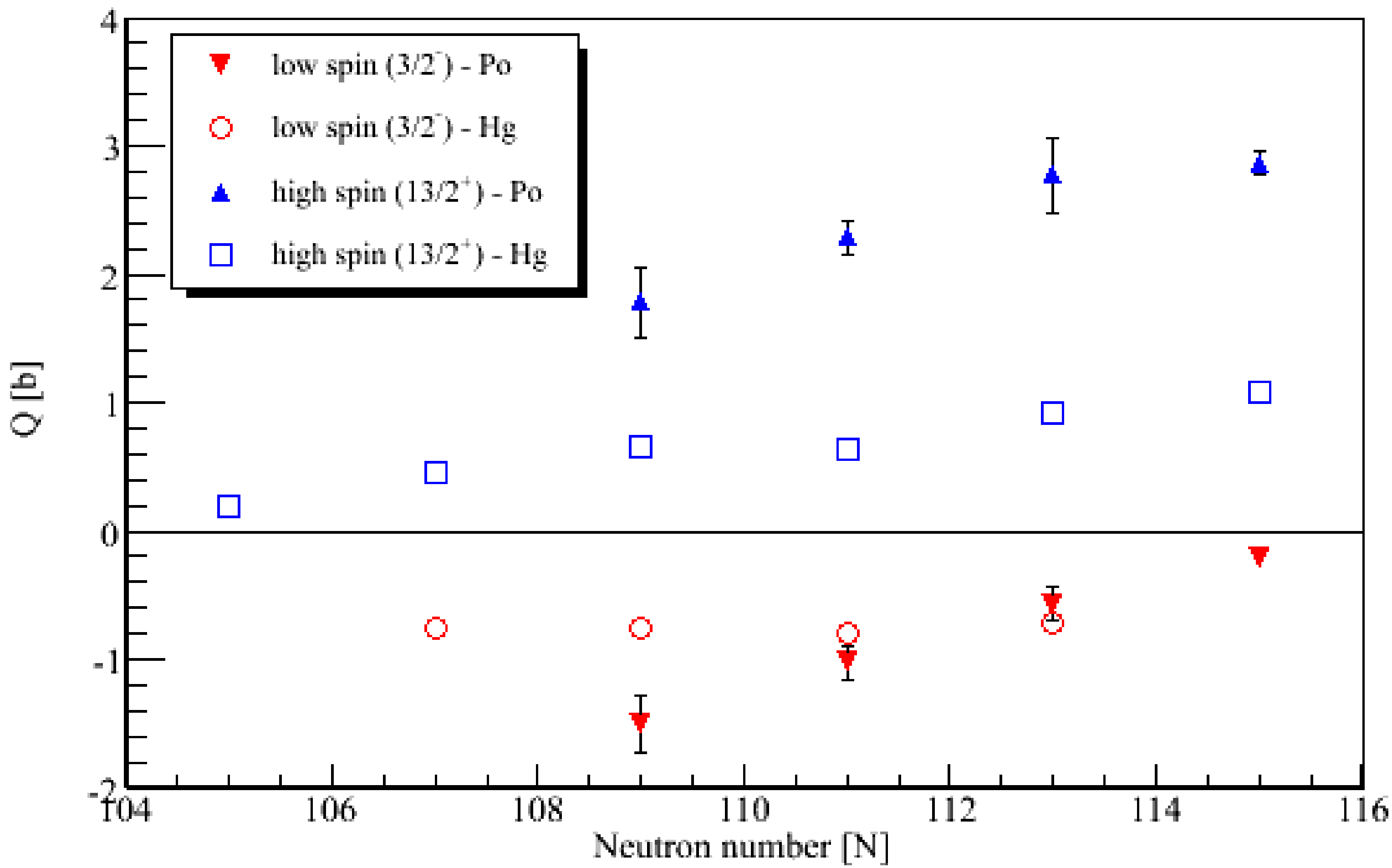
No extreme isomer shift is observed.

Precision of the centroid is greatly affected by the complicated hyperfine structure.

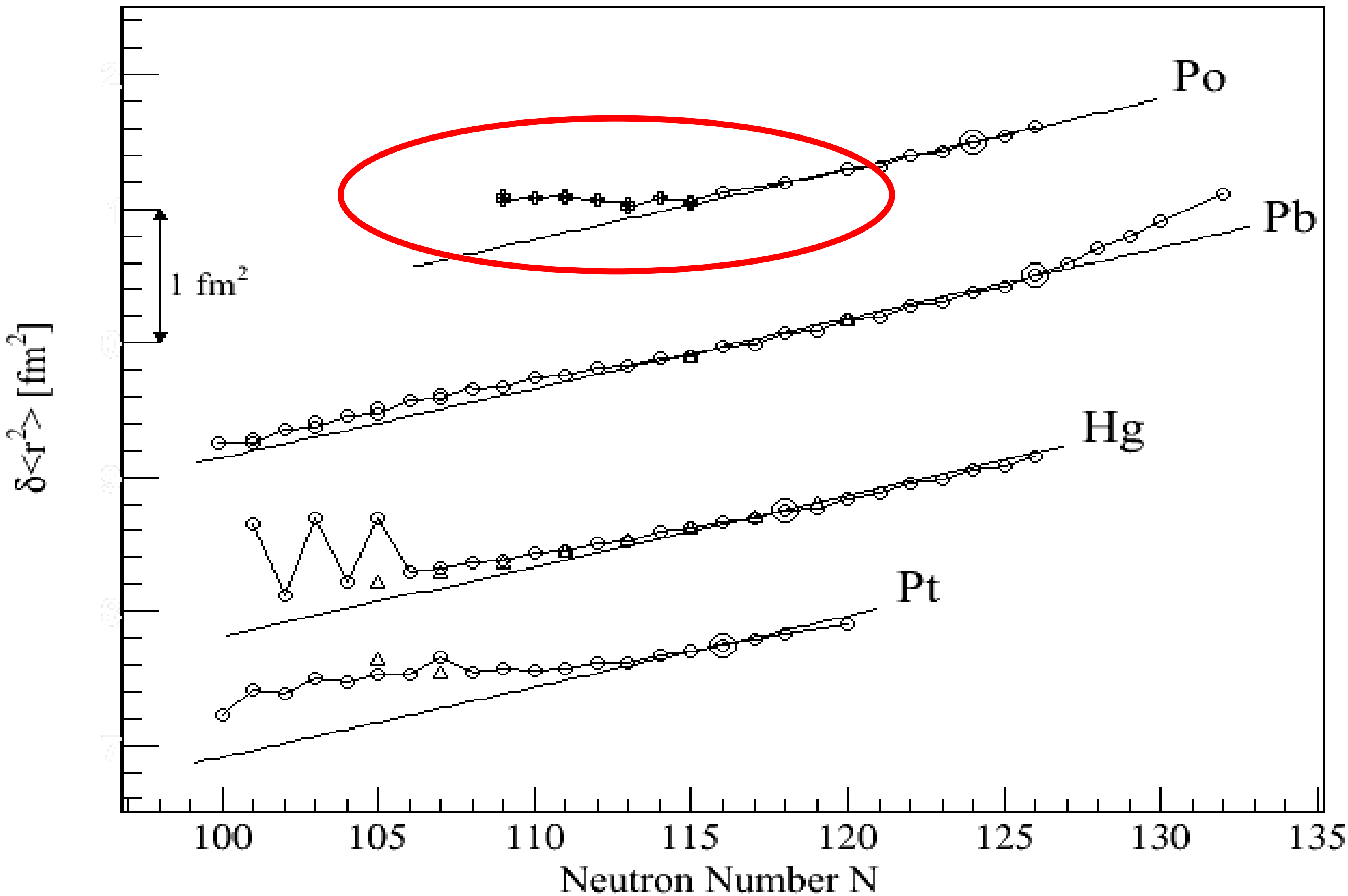
Magnetic dipole moments



Electric quadrupole moments



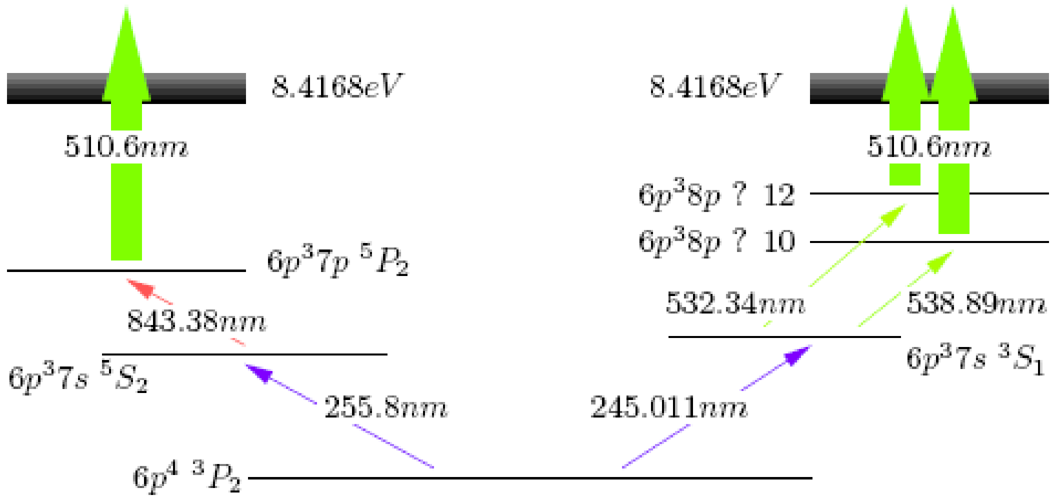
Mean-square charge radii

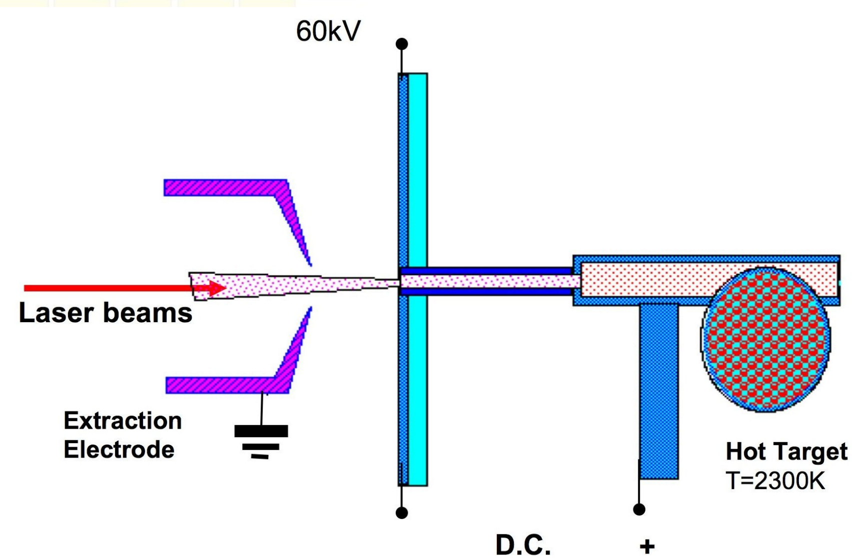


Conclusions & Outlook

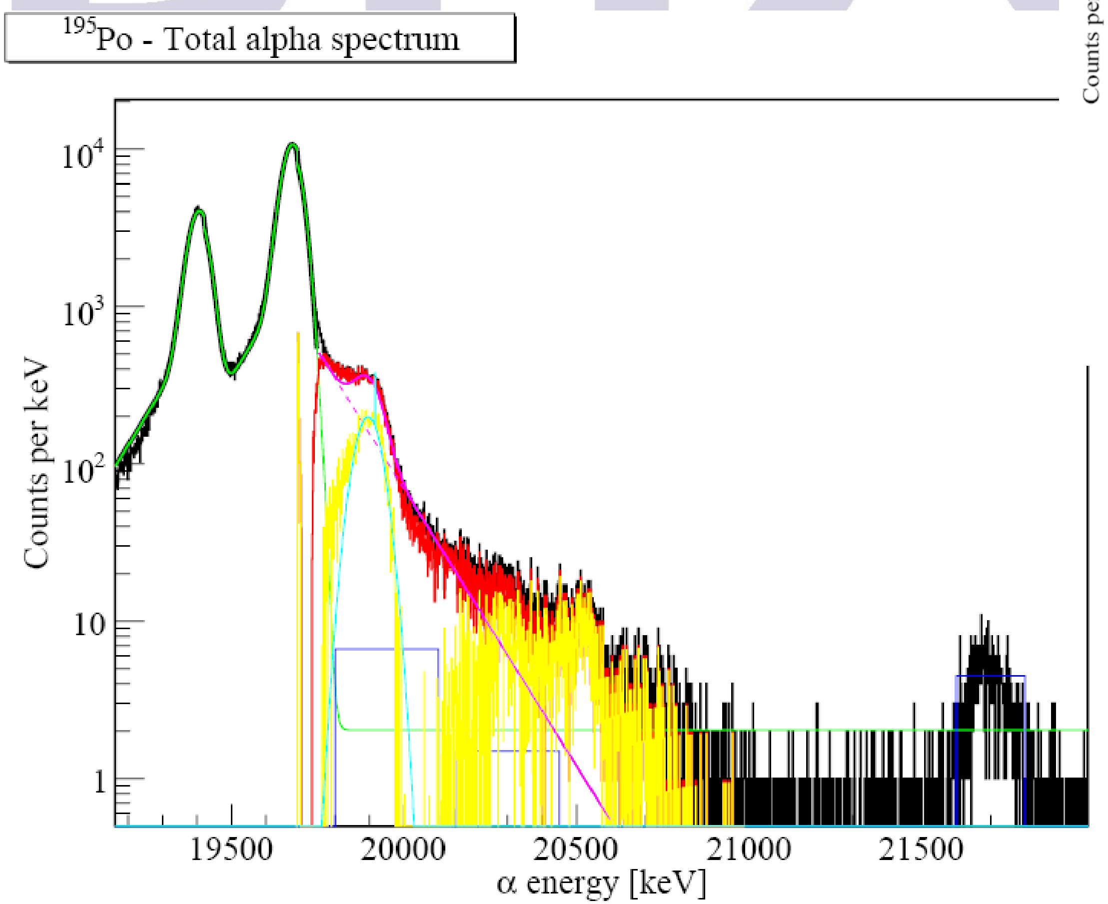
- LOTS of information can be extracted !! and the analysis is still under way...
- Further the analysis
  - Corrections on the optical spectra
  - Compare the *F* factor to theoretical predictions
- Lift the ambiguities
  - Cross-over decay in ^{195}Po
  - Spin of the odd isotopes
- Relate to the nuclear models
  - Mean-field calculations
  - IBM
  - Clusters
- Further studies
  - ? In-source spectroscopy of ^{192}Po
  - ? In-source spectroscopy of the missing links $^{201\text{-}203\text{-}208\text{-}209\text{-}210}$Po
  - ? In-source spectroscopy of neutron-rich $^{216\text{-}217\text{-}218}$Po
  - ? Collinear spectroscopy using ISCOOL – the new cooler-buncher at ISOLDE.
  - ? Coulomb Excitation with MiniBall at REX-ISOLDE

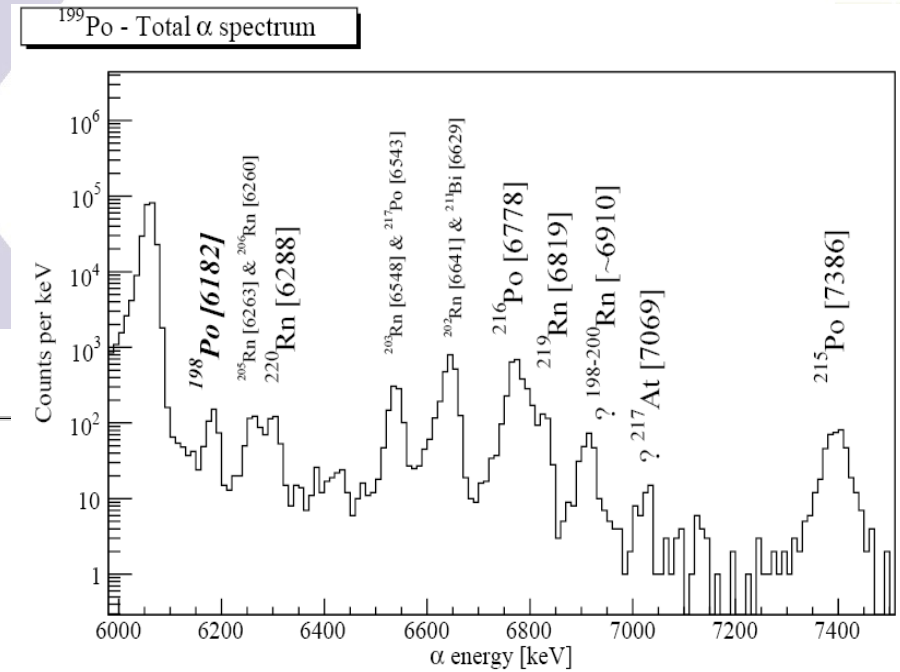
ISOLDE RILIS



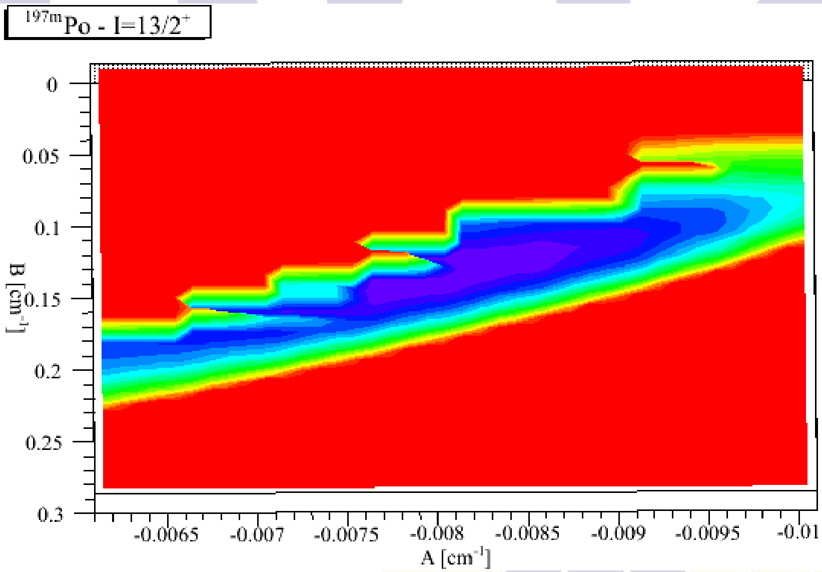


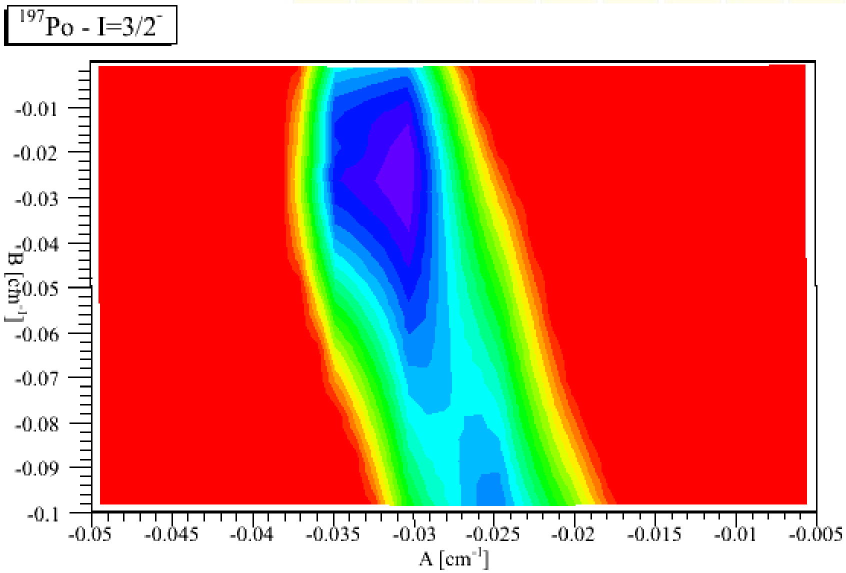
Cross-over decay in ^{195}Po





χ^2 map of the HFS





HFS

$$\Delta E=\frac{A\cdot K}{2}+\frac{B\cdot(\frac{K\cdot(K+1)}{2}-2I\cdot(I+1)\cdot J\cdot(J+1))}{(2I\cdot(2I-1)\cdot 2J\cdot(2J-1))}$$

$$K=F\cdot(F+1)-I\cdot(I+1)-J\cdot(J+1)$$

$$\frac{(A(19x))}{(A(207))}=\frac{[\frac{(\mu_I(19x))}{(I(19x))}]}{[\frac{(\mu_I(207))}{(I(207))}]}$$

$$\frac{(B(19x))}{(B(207))}=\frac{(Q(19x))}{(Q(207))}$$

Po

A	Ground state μ_I $[\mu_N]$	Ground state Q $[b]$	Isomer state μ_I $[\mu_N]$	Isomer state Q $[b]$
193	-0.422	-1.27	-0.567	1.62
195	-0.646	-1.09	-0.894	2.31
197	-0.928	-0.71	-0.956	2.85
199	-0.850	-0.84	-0.743	3.37

A	μ_I $[\mu_N]$	Q $[b]$
205	0.760	0.17
207	0.793	0.28
209	0.606	0

Hg

A	Ground state μ_I $[\mu_N]$	Ground state Q $[b]$	Isomer state μ_I $[\mu_N]$	Isomer state Q $[b]$
185	0.509		-1.017	0.20
187	-0.594	-0.75		0.45
189	-0.6086	-0.76		0.66
191	-0.618	-0.80		0.64
193		-0.72		0.916
195			-1.045	1.08
197			-1.028	1.24
199	0.4979		-1.015	1.18
201	-0.5513	0.385		
203		0.343		